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BORANG PENGESAHAN
LAPORAN AKHIR PENYELIDIKAN

TAJUK PROJEK : ......Driver's Car Following Headway on Single Carriageway Roads

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VOT 71620

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(JARAK MENGEKOR PEMANDU KENDERAAN DI ATAS JALAN TUNGGAL)

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ABSTRAK

Laporan ini menerangkan penyelidikan untuk mengkaji kelakuan pemandu di atas jalan raya tunggal rural. Kajian telah dijalankan dengan skop yang bermatlamatkan untuk mengenal pasti jarak pemisahan antara kenderaan terkekang di atas jalan-jalan tunggal. Model empirikal dibentuk bagi menggambarkan jarak mengekor pemandu kenderaan pada pelbagai kelajuan. Data yang menerangkan jarak kepala dan kelajuan bagi lebih daripada 8000 kenderaan telah dicerap menggunakan kamera video untuk merakam pergerakan lalu lintas di empat lokasi di Malaysia. Pita video yang mengandungi rakaman lalu lintas diproses di makmal dan data disari menggunakan program komputer perakam peristiwa. Semua data ditapis bagi mendapatkan data dan maklumat yang berkaitan kenderaan yang terkekang sahaja. Jarak kepala dan kelajuan kenderaan yang berkait dengannya diasingkan kepada kategori kenderaan mengekor menurut jenis kenderaan dan kemudiannya diasingkan kepada kelas-kelas kelajuan bagi kategori kenderaan mengekor kenderaan, kereta mengekor kereta, kereta mengekor HGV, HGV mengekor HGV dan HGV mengekor kereta. Dalam kebanyakan kes taburan log-normal didapati wakil yang sesuai bagi perubahan jarak kepala untuk kenderaan-kenderaan dalam satu-satu kelas kelajuan tertentu. Model-model regresi linear dibentuk bagi mewakili kehubungan di antara jarak kepala dan laju kenderaan. Model seterusnya mewakili ramalan perubahan dalam populasi jarak kepala dan laju. Hasil kajian dibandingkan dengan kajian-kajian terdahulu dan implikasi yang mungkin dalam analisis operasi lalu lintas di atas jalan raya tunggal dibincangkan. Secara umumnya, hasil kajian memberikan kenyataan bahawa kebanyakan pemandu di atas jalan raya tunggal di Malaysia mirip untuk mengekori kenderaan di hadapannya pada jarak yang rapat. Deretan-deretan kenderaan kelihatan terbentuk dengan cepat. Maklumat yang terkumpul dalam kajian ini sangat berguna kepada jurutera dan jururancang lalu lintas dalam menangani isu keselamatan jalan raya dan analisis operasi lalu lintas.

ABSTRACT

This report describes research to investigate drivers' behaviour on rural single carriageway roads. The study was carried out with the scope aiming at deriving the distance separation between impeded vehicles on single carriageway roads. Empirical models were developed to describe the driver's car-following distance at various operating speeds. Data defining headway and speed for more than 8000 vehicles were collected, using video cameras to record traffic movement at 4 sites in Malaysia. The video cassettes containing the traffic scenes were played-back in laboratory and data were extracted using a computer event recorder. All data were filtered to provide data and information for impeded vehicles only. The distance headways and associated vehicle speeds were separated into vehicle following category by vehicle type and then into speed classes for vehicle following vehicle, car following car, car following HGV, HGV following HGV and HGV following car categories. In most cases the lognormal distribution was found to be an appropriate representation of the variation in distance headways for vehicles within a particular speed class. Linear regression models were developed to represent the relationships between distance headway and speed and hence to represent the predicted variation in population mean distance headway with vehicle speed. The results were compared with those from other studies, and the possible implications for single carriageway road traffic operational analysis were considered. In general, the results of the study provide evidence that most Malaysian drivers tend to follow another vehicle closely on single carriageway roads. Platoons appeared to develop rapidly. Such information gathered from the study is useful for traffic engineers and planners in addressing traffic safety issues and traffic operational analysis.

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CHAPTER ONE

INTRODUCTION

Most traffic operational analyses relate to many aspects of vehicles and drivers behaviour in traffic streams. One of many aspects that are considered to influence road crashes and road traffic handling capacity is the drivers' car following behaviour. However, in most countries, the behaviour of the local drivers is not considered explicitly in the analysis, especially in the highway capacity analysis, as the method used is adopted directly from the American Highway Capacity Manual. This study addresses the driver's car following behaviour on rural single carriageway roads for the local environments.

1.1 Problem statement

Two aspects that are of the main concerned of road traffic engineers and planners are road safety and road traffic handling capacity. Both analyses are associated with the behaviour of the road users either directly or indirectly. In most cases the analysis of road traffic safety issues is often based on a non-dynamic driver's car following behaviour concept. The driver's car following distance, for instance, is often considered as not related to the speed at which a vehicle travels. On the other hand, the road capacity analysis is based on the American Highway Capacity Manual which is formulated based on American traffic environment (Transportation Research Board (TRB), 1994). Such approaches would lead to an inaccurate evaluation of the problems and hence would result in incorrect planning of improvements. Studies of local traffic behaviour, therefore, have to be carried out to incorporate in the analyses of road safety and capacity.

1.2 Aim and objectives

The aim of this study is to investigate and to develop the drivers' car following behaviour in terms of mathematical relationships between car following headway and vehicle speeds on rural single carriageway roads in Malaysia. To achieve this aim, the study was carried out with the following objectives:

- to collect, extract and collate data describing headways and their variation with the main influencing variables, on single carriageway roads,
- to develop statistical relationships defining the distance separation vehicles travelling at similar speeds where the progress of the follower is impeded by the leader (i.e. car following headway) based on the observed data for single carriageway roads, and
- to evaluate the possible effects on current practices of traffic operational analyses

1.3 Importance of the study

The results of the study will be in a form of empirical models of driver's car following headway on rural single carriageway roads in Malaysia. Such models would be useful for the analysis of road traffic safety and road traffic handling capacity for local road network systems. The considerations of local traffic behaviour would, therefore, result in accurate assessment of deficiencies in local road and traffic operations and hence allow efficient planning and management of resources.

1.4 Scope of study

The study focuses on traffic operations on rural single carriageway roads. Roads considered in the study are of state roads and federal roads R3 or R4. Motorcyclists are not considered in the study. Aspects to be considered are headways and the associated vehicle speeds in traffic streams.

CHAPTER TWO

LITERATURE REVIEW

Understanding of drivers' car following behaviour is essential, as it is the most frequent phenomena that can be observed in traffic streams. This Chapter describes the theoretical aspect of the related behaviour and its applications in the context of traffic engineering studies. Some major studies from abroad are also discussed.

2.1 Drivers' interactions in traffic streams

Drivers' car following behaviour is the processes of following drivers attempt to adjust to the behaviour of the leading vehicle. In a situation where the volume of traffic is light or in a free flowing condition, driver's selection of speed is usually constrained by such factors as the road geometry features, lighting, and weather conditions. The attainable speed is only constrained by the driver's desired speed and the performance of a vehicle when negotiating the different road alignment.

In situations where the manoeuvrability of a driver is influenced by the vehicles ahead of him, the driver needs to adjust speed and position to keep a safe following distance at all times (i.e. to avoid rear-end collision with the preceding vehicle). This is termed as driver's car following distance or headway. The phenomena can be observed when a faster vehicle catches up, and cannot immediately overtake, a slower vehicle in a traffic stream. This impeded vehicle is usually, by definition, has a desired speed higher than that of the leader.

On single carriageway roads, vehicle platoons form most rapidly in a situation where traffic flow is high and overtaking opportunities are limited. By definition, a platoon is a group of successive impeded vehicles travelling at a similar speed (Hunt, 1997). As described by Hunt (1997), a vehicle travelling at the driver's desired speed will catch up vehicles travelling at lower speed. In a situation where overtaking is not possible, the driver of the vehicle travelling at higher speed must reduce his/her speed to match the speed of the leading slower vehicle. The distance between the two vehicles will decrease during this period of deceleration. Hunt (1997) defined this range of distance as the zone of influence. When deceleration is complete the vehicles will travel at approximately similar speed. Although in practice the distance will vary as the follower adjusts to changes in speed of the leader, it is assumed that the follower will maintain steady state constant distance headway with the leader. This interaction between drivers in platoons maintain until the follower overtakes the leader.

2.2 Empirical relationships between following headway and speed

Drivers' car following behaviour has been studied and modelled by numerous researchers over the past decades (e.g. Gazis et al, 1961; May et al, 1967; Köhler, 1979; Gipps, 1981; Miyahara, 1994). The studies and models varied in objectives and ranged from an empirical approach to complex mathematical and simulation modelling approaches. Because empirical studies usually concern the analysis of the real data, car following behaviour derived from such studies are referred to, as drivers' preferred following distance.

In 1949 Smeed and Bennett, as reported by Lane (1968) and Hunt (1997), derived a steady state driver's following distance in the form of

$$H = 5.34 + 0.792V + 0.01221V^2 \qquad (2.1)$$

Where H is the distance headway in metres and V is vehicle speed in m/s.

Daou (1966) suggested that the distribution of the vehicle distance headway under constrained traffic situations could mathematically be represented by a log normal distribution whose standard deviation is dependent on the speed. His suggestion was based on an assumption that the following driver allows a constant reaction time and a constant buffer distance at all speeds. Daou derived a median (and hence taken as mean) following distance relationship based on a study of the behaviour of traffic through a tunnel. His vehicle following distance relationship is written as,

$$H = 1.37V + 10.338 \qquad (2.2)$$

where V is in m/s. Daou suggested that the coefficient and the constant in *Equation (2.2)* are interpreted as the driver's reaction time and length of the leading vehicle plus a safe buffer distance, respectively.

A constant following distance relationship has been used as the basis of the Scottish REVS model (Halden, 1995) for traffic on single carriageway section. The model was based on the assumption that following distance does not vary with speed, and that all vehicles have the same length. The model is given by:

$$H = L + 10 \qquad (2.3)$$

where H is the distance headway measured in metres from rear to rear, and L is the length of the vehicle which is taken as 4 metres for a car (the length of an HGV was not mentioned).

Equation (2.3) appears unrealistic and does not represent actual driver behaviour. Speeds are assumed all equal and the spacing is assumed independent of the speed. Consequently, traffic volume in this case increases linearly with speed.

Mahdi (1991) suggested that the finding by Daou might be taken to represent a normal car following situation, i.e. a case where the following driver has no intention to overtake the leading vehicle. To avoid being too conservative in terms of vehicle safe following distance Mahdi observed car following situations during overtaking manoeuvres. Such car-following situations (i.e. often referred to as close car following or 'tailgating') describe the 'safe' minimum following distance adopted by the potential overtaking drivers. Mahdi proposed the following equations to represent close car following situations.

$$H_C = 0.305V + 9.364 \qquad (2.4)$$

$$H_H = 0.353V + 13.620 \qquad (2.5)$$

where H_C and H_H are the mean following distance in metre for a vehicle following a car and a vehicle following an HGV respectively, and V is speed in m/s.

It is noticeable that *Equations (2.2)*, *(2.4)* and *(2.5)* are similar in terms of vehicle separation at zero speed, which ranges from 9.364 to 13.62 metres. This range of vehicle separation appears to include the effect of the length of the leading vehicle. Both *Equations (2.4)* and *(2.5)* were derived from the headway data, which are log normally distributed.

Hunt (1997) carried out a thorough study of driver following behaviour for Great Britain's single carriageway roads in 1997. He suggests four types of car following distance relationships:

Car following car:	$H_{CC} = 2.124V - 4.31$	(2.6)
Car following HGV:	$H_{CH} = 2.052V + 1.156$	(2.7)
HGV following HGV:	$H_{HH} = 2.79V - 3.997$	(2.8)
HGV following car:	$H_{HC} = 2.854V - 8.15$	(2.9)

where distance is measured in metres from front to front, and V is speed in m/s.

Although the relationships are consistent with those proposed by Daou (1966), Smeed and Bennett (Lane, 1968), and Mahdi (1991) they do not indicate vehicle separation at zero speed. To overcome this shortcoming Hunt suggested that the applicability of the relationships is only valid for vehicle speed greater than 20 km/h. He also suggested that the use of a mean spacing of vehicle length plus 10 metres buffer for speed below 30 km/h would be appropriate.

To summarise, driver's car following distance obtained from the studies described in this section are plotted in Figure (2.1). The safe car-following distances based on Highway Code (Macpherson, 1993) are also plotted for comparison.

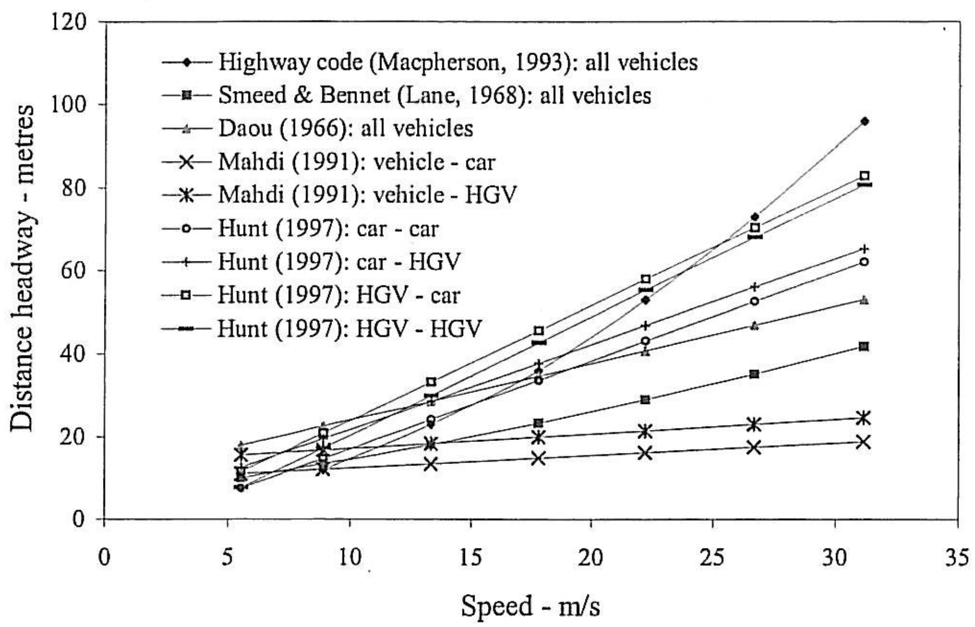

Figure 2.1: Drivers' car following distance from previous studies

Figure (2.1) shows that Hunt's drivers' following distance do not differ much from those of Daou or from those suggested by the Highway Code although the Highway Code gives greater spacing at higher speed as it is based on theoretical safe braking distance under good driving conditions. Hunt's data show that, at a specified speed, the following distance preferred by a driver varies according the types of vehicle driven and vehicle being followed.

These deterministic car-following distance relationships are a result of a simplification process, particularly with respect to the relationship between spacing, and the driver observation-reaction process. However, the advantage of such relationships is that they are easy to deal with.

2.3 Applications of headway and speed relationships

This Chapter will not consider specific applications of headway and speed relationships in detail. However, it should be pointed out that such relationships are among the fundamental elements of road traffic safety studies and road traffic capacity analyses. Gazis et al (1961), May et al (1967), Köhler (1979), Gipps (1981), Mahdi (1991), Miyahara (1994), Halden (1995), Hunt (1997), and Othman Che Puan

(1999) are several examples of studies which provide detailed descriptions of applications of headway and speed relationships in the analysis of road capacity and in road traffic operational analysis. The relationships are also an important element in the modelling of road traffic operation.

2.4 Concluding remarks

This Chapter has provided some insights into the behaviour of drivers on rural single carriageway roads. Several studies of car-following headway in traffic streams have been reviewed. It was stated in Chapter 1 that one of the objectives of the current study is to established relationships defining driver's following headway on single carriageway roads for local environment. The studies by previous researchers described in this Chapter provide the basis for data collection and analysis in the current studies.

CHAPTER THREE

METHODOLOGY

The preceding chapters provide the brief background of the related studies carried out elsewhere. The chapters have also described the major aspects that are considered in this study. It is generally acceptable that the data and information required in any studies may be obtained from two sources: (a) from direct observations and/or, (b) from previous studies. The following subtopics describe the type of data and methodology adopted for the study.

3.1 Type of data required

The data that are required for the development of the relationships between distance separations of vehicles and speeds in this study are as listed below.

- *Headway*

In this study, headway is defined as a time or distance separation between the fronts of two successive vehicles passing a same point on a roadway.

- *Speed*

Speed is the rate travel of an individual vehicle measured in km/h.

- *Vehicle type*

Vehicles in this study are classified based on types that are commonly used for road capacity analysis. However, for the analysis, vehicles are grouped into two major types, i.e. cars (a vehicle having not more than 2 axles or having a total of not more than 4 wheels) and HGV (a vehicle having more than 2 axles or more than 2 wheels on the rear axle).

3.2 Field studies

3.2.1 Objectives of the field studies

The previous chapter has discussed the functions defining the relationships between headway and speed found from several previous studies of traffic operations on single carriageway roads. It is clear that the findings from most of these studies require further revision with more recent data for a general conclusion to be reached. Therefore, this field exercise was carried out to collect and analyse all the traffic data pertaining to the development of empirical relationships between headway and speed for Malaysian traffic conditions.

An accurate measurement of drivers' choice of following distance and speed requires extensive field observations and a large quantity of headway data. However, because of limitation in time and resources, the quantity of data to be collected for this study is a compromise between a reasonable, realistic data collection effort and the need for adequate data for numerical analysis.

3.2.2 Selection of the studied sites

Several visits were made to the various stretches of single carriageways in Peninsular Malaysia. The intention was to identify suitable sites for data collection purposes. In other words, the main objective in selecting sites was that the sites should be representative of rural single carriageway roads and that road layout and traffic would provide a high proportion of impeded vehicles. Therefore, for this study the selection of road stretches to be studied was based on the following criteria:

(a) road sections with less than 30% overtaking provision,
(b) road sections with sight distances of less than 200 m,
(c) roads carrying a high proportion of long distance trips,
(d) roads with a high traffic volume,
(e) roads with standard width and layout and representing a range of geometric design in terms of alignments,
(f) good access and safety for the enumerators and equipment during the data

collection process,

(g) good overhead vantage points for video recording purposes,

3.2.3 Field data collection procedure

In this study, field data collections were carried out using video cameras. Othman Che Puan (1999) has described the advantages of using a video recording method for traffic data collection. One particular difficulty with the method is in finding a suitable vantage point with good visibility to acquire the data. This problem was the major factor affecting the type of data obtained for this study.

At each location, two video cameras were mounted unobtrusively at roadside providing a side – on record the passage of vehicles. The cameras were located at distances apart which ranged between 50 m and 200 m. The exact location of cameras at each location was influenced by logistics such as vegetation, visibility, etc. On each occasion data were collected only for the nearside vehicles.

An external time device, i.e. a character generator, was attached to each camera to provide a permanent record of stopwatch. The reference points at which the headway data were measured were marked using the road cones. Figure (3.1) shows the schematic diagram a typical arrangement of the cameras' set up adopted during the field observation exercises.

On each occasion, traffic data were recorded for three periods of time of day, i.e. between 8.00 am to 10.00 am, 12.00 noon to 2.00 pm and between 4.00 pm to 7.00 pm. These recording periods were considered appropriate for evaluating the required traffic parameters under a range of traffic flows.

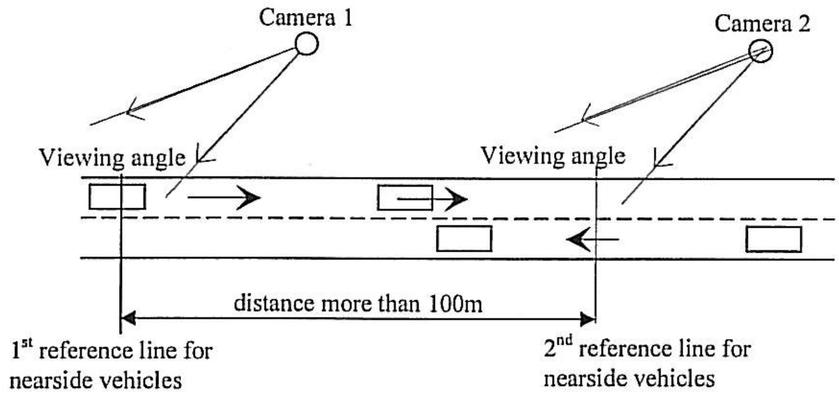

Figure 3.1: Arrangement of cameras on site during video recording process

3.3 Data abstraction and processing

Each of the videotapes containing the recorded scenes was played back to retrieve the relevant data. For each vehicle it was required that the vehicle classification, following headway (measured in term of time), and speed are defined. This was achieved using a computer-based event recorder to extract data defining vehicle arrival time and classification from the video recording of traffic scene at each of two positions for each location. As required for the analysis, vehicles were classified as HGV (heavy goods vehicle) or car. An HGV is a vehicle identified as having more than 2 axles, or 4 wheels on the rear axle. A bus is recorded as an HGV. Motorcycles are excluded from the analysis.

For vehicle arrival at each detection line, the videotapes were played back in real-time. A vehicle arrival time was recorded by pressing a pre-defined key each time the front of a vehicle reaches a specified reference line. All vehicle arrival time data at two consecutive detection lines were extracted using the same time reference for all directions of traffic. This was an important procedure because all events have to be arranged in a correct order based on the individual occurring times for time headway analysis.

For each data extraction and analysis process, the data were stored on a text-formatted data file. This was done by transferring to an Excel spreadsheet all the recorded data for arrival time and classification at each of the two positions for each measurement. The data for each vehicle were matched and the time headway at each position and vehicle speed between positions were calculated. Time headways were measured as the time between the passages of the fronts of successive vehicles. This is based on the definition given by the TRB (1994) i.e. headway is the time between successive vehicles in a traffic stream, as measured from front bumper to front bumper. This method of measurement of headway includes the inter-vehicle distance and a vehicle length. The speed of each vehicle was computed using the time taken to travel between the two consecutive detection lines.

The headway and speed data were evaluated for the individual vehicles. A preliminary data analysis was carried out using Excel spreadsheets to evaluate the validity of headway and the corresponding speed to identify unrestrained and impeded vehicles in the traffic stream and to evaluate the inconsistencies in the tabulations of the data.

3.4 Concluding remarks

This Chapter describes the methodology adopted for the study. The following Chapter discussed the results of the data collections and analysis.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

Chapter 3 has described the methodology adopted in the study. This Chapter discusses the results of the data collection, analysis, and interpretations.

4.1 The survey sites

Four sites were selected as the observed road section in the study. Table (4.1) provides the summary of the general characteristics of each section. The maximum speed limit on all road sections are 90 km/h. Except for Site No. 4, all other road sections carried relatively high traffic volumes during peak hours.

Table 4.1: The survey sites

Site No.	Location	Average road width – m (no. of lanes)	Approximate section length - m	Observed stream	Road characteristics upstream (lane marking)*	Road characteristics in section (lane marking)*
1	Kuantan – Pelabuhan Bypass	7.0 (2)	500	Both	Flat, straight (DC)	Flat, straight (SS)
2	Kangkar Pulai – Pontian, Johor	7.0 (2)	300	Both	Flat, straight (SS)	Flat, bendy (DC)
3	Kangkar Pulai – Pontian, Johor	7.0 (2)	250	Both	Flat, straight (SS)	Uphill, straight (DC)
4	Yong Peng – Segamat, Johor	7.0 (2)	500	Both	Flat, straight (SS)	Flat, straight (SS)

*Note: SS Short single broken line

DC Double continuous line

The surveys were carried out during weekdays and under good weather conditions. A total of 8511 vehicles were observed. All roads carried relatively high proportions of

HGV during peak hours (i.e. in the range of 15 to 20 percent).

4.2 Data overview

The collected headway and speed data for 8511 vehicles is a mixture of restrained and unrestrained vehicles. It is already mentioned that the following behaviour of a driver can only be observed in a situation where the follower is impeded by its leader, or the following vehicle has entered the zone of influence. Therefore, the analysis will only consider the headway data for the impeded or restrained vehicles. This requires the headways data for the impeded following vehicles are first separated from the headways for the free flowing or unrestrained vehicles. There is no specific method of identifying vehicles which are impeded by their leader in a traffic stream (Hunt, 1997). However, it is generally accepted that most impeded vehicles are at relatively very small time headways and will travel at a speed relatively similar to their corresponding leader. The Highway Capacity Manual (TRB, 1994) suggests that the headway of 5 sec or less represents a vehicle which is impeded by its leader. Hunt (1997) uses the ratio of speed of follower to the speed of the leader in addition to the maximum time headway cut-off point to differentiate the impeded and unrestrained vehicles. An approach similar to Hunt (1997) was adopted in the study to filter out the impeded vehicles, i.e.:

- time headway of less than or equal to 5 sec.; and
- ratio of speed of follower to speed of leader ranging between 0.9 and 1.02

The impeded vehicle headways were analysed for all types of vehicle and were also grouped according to the type of vehicles to produce another four sets of headway data. The frequencies are as below.

- all vehicle with a frequency of 3879
- car following car with a frequency of 2259
- car following HGV with a frequency of 866
- HGV following HGV with a frequency of 278

- HGV following car with a frequency of 430

Figure (4.1) shows scatter plot for the data points in all vehicle data set after filtering out the time headways greater than 5 sec. The equivalent distance headways were computed using the corresponding speeds and the scatter plot of the distance headway for the impeded vehicles is shown in Figure (4.2). In terms of distance, the data from this study indicated that the impeded vehicles are at headways not greater than 130 m.

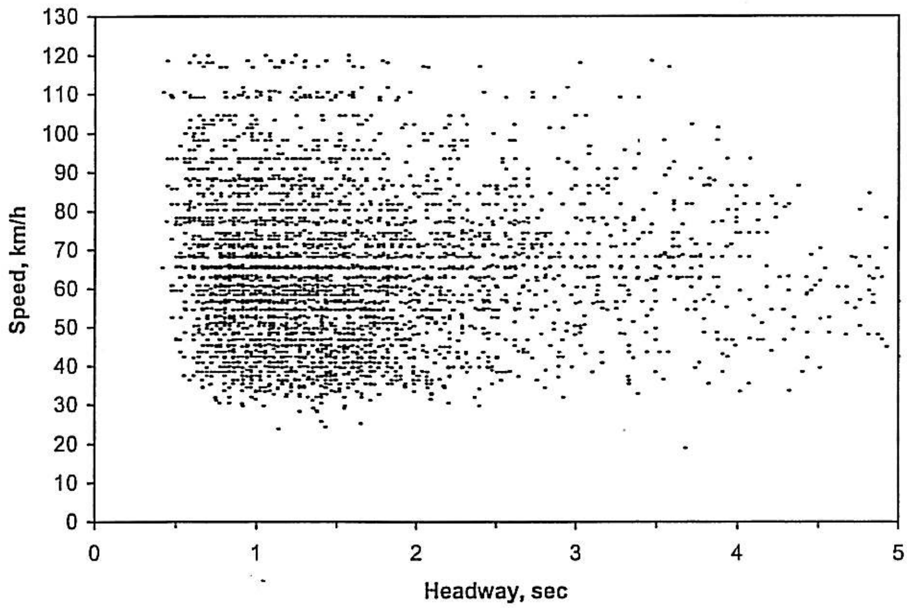

Figure 4.1: Scatter plot for time headway less than 5 sec (all vehicles)

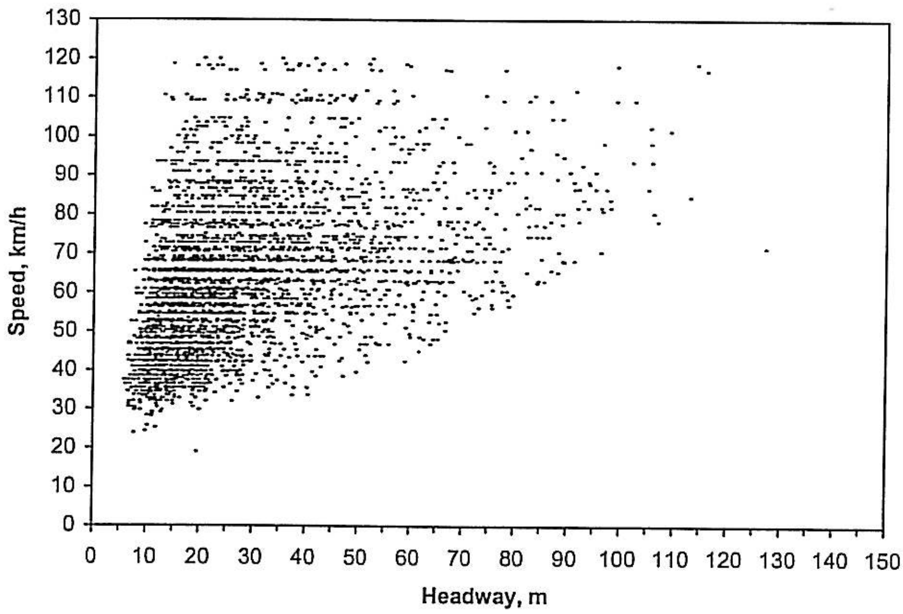

Figure 4.2: Scatter plot for distance headway less than 130 m (all vehicles)

4.3 Distributions of speed and headway of impeded vehicles

The distribution of speeds of all impeded vehicles was plotted as shown in Figure (4.3). As expected, most impeded vehicles are found to travel at relatively low speeds. In the analysis the speed class widths were determined to retain reasonable sample frequencies for each class. Within each speed class for each of the vehicle following types, the distance headway data were allocated to the frequency distributions shown in Figures (A.1) – (A.5) in Appendix (A). For each speed class the headway data belongs to it are grouped into headway classes. The summaries of descriptive statistics for data in each of speed classes for each of vehicles following types are provided in Appendix (B).

A typical plot of the distribution of the distance headway data for all vehicles in speed class 50 – 60 km/h is shown in Figure (4.4). The distance headway frequency distributions are all positively skewed. As suggested by Daou (1966), each of the distributions is visually similar to distributions represented by a lognormal distribution. A lognormal distribution is the distribution of a variate whose logarithm obeys the normal law of probability (Hunt, 1997).

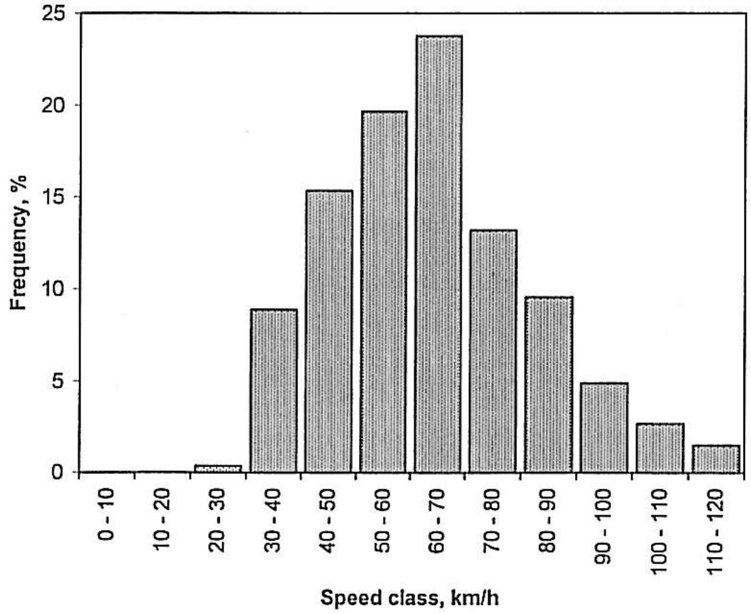

Figure 4.3: Distribution of speeds for all vehicles

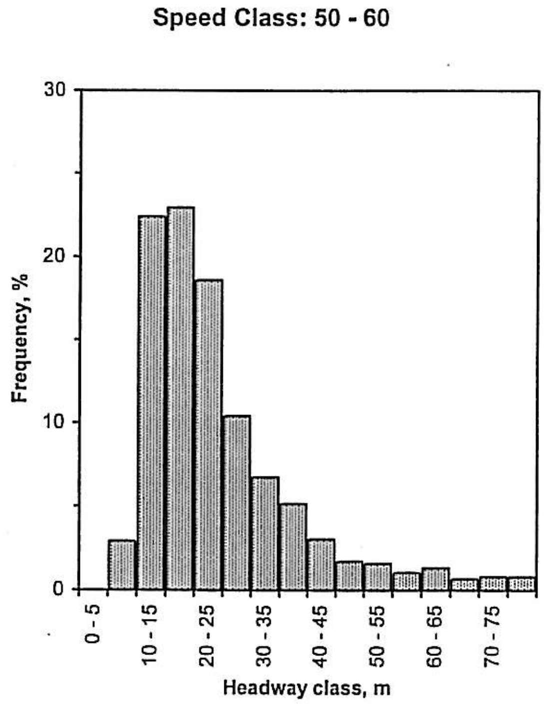

Figure 4.4: Distance headway for all vehicles in speed class 50 – 60 km/h

4.4 Derivations of car following models

The relationships between headway and speed developed in the previous studies have been discussed in Chapter 2. In general, most studies demonstrated that the relationships are in a form of a regression model, i.e.:

$$H = A_0 + A_1 V \tag{4.1}$$

where H is the distance headway,

V is the speed of vehicle,

A_0 is representative of vehicle length, and

A_1 is representative of a driver reaction time.

This study applied the regression analysis to each of the data set representing each of the following types in an attempt to develop mathematical models similar to *Equation (4.1)*. It should be pointed out that some studies considered the relationship in a quadratic form to include an additional term related to vehicle's ability to brake (e.g. Smeed and Bennet (Lane, 1968) to name one of those.) However this approach was not considered as the term was found statistically insignificance in the formulation of the relationship.

This study derived a median (and hence taken as mean) following distance relationship. The median headway in each speed class was used in view that the arithmetic mean would lead to a bias interpretation of log-normally distributed data. This approach is similar to the approach adopted by Daou (1966). Figures (4.5) and (4.6) show the relationships between headways and speeds for cases of a vehicle following a vehicle and a car following a car, respectively. The plots for other types of following vehicles are given in Appendix (C). Table (4.2) provides the summary results of the regression analysis for all types of following vehicles considered.

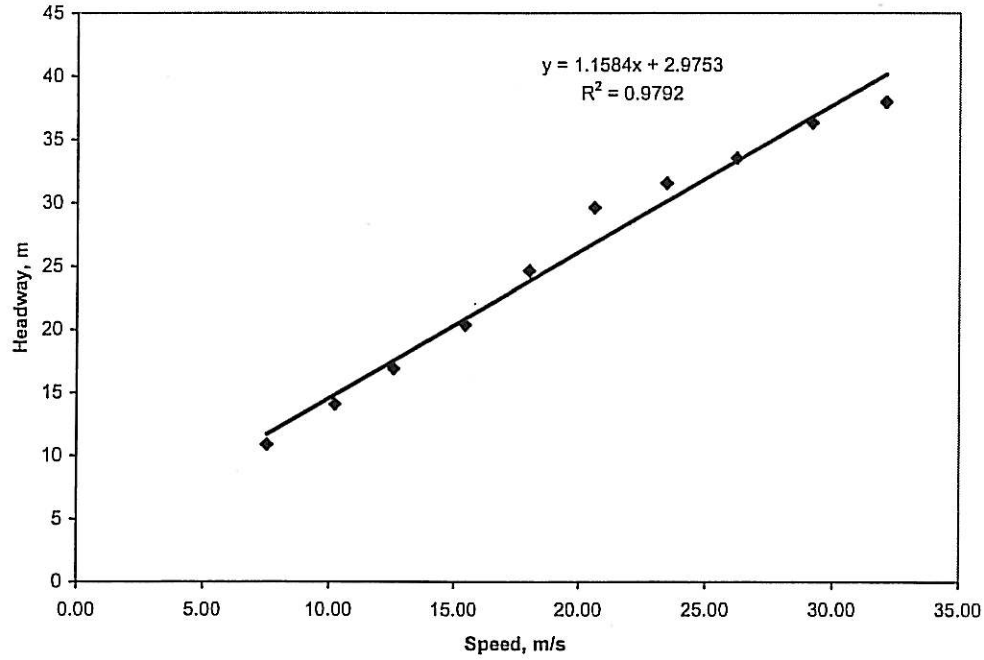

Figure 4.5: Headway and mean speed for each speed class (all vehicles)

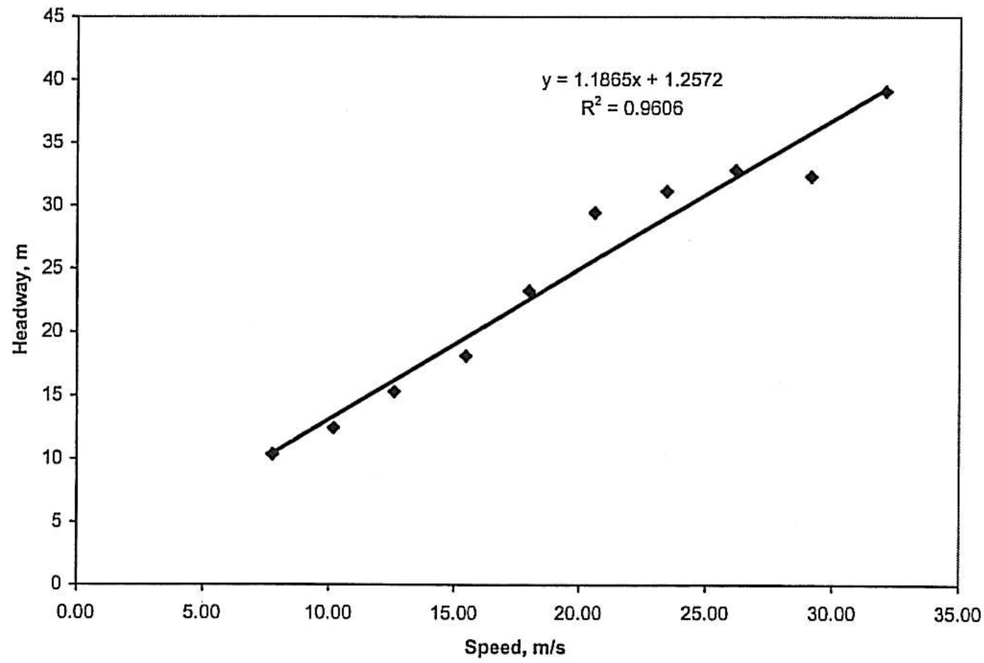

Figure 4.6: Headway and mean speed for each speed class (car following car)

Table 4.2: Regression results for each type of following vehicles

		Headway = $A_0 + A_1V$		
Following type	*Sample size*	A_0 ( )	A_1 ( )	R^2
All vehicles	3879	2.98 (3.95)	1.16 (0.19)	0.98
Car – Car	2259	1.26 (5.66)	1.19 (0.28)	0.96
Car – HGV	866	4.04 (1.96)	1.12 (0.11)	0.99
HGV – HGV	278	9.33 (11.19)	1.21 (0.61)	0.85
HGV – Car	430	5.17 (12.96)	1.19 (0.69)	0.81

Note: ( ) standard deviation

Mathematically, the results of the regression analysis shown in Table (4.2) may be written as follow:

$$H_{(\text{all vehicles})} = 2.98 + 1.16V \qquad (4.2)$$
$$H_{(\text{car - car})} = 1.26 + 1.19V \qquad (4.3)$$
$$H_{(\text{car - HGV})} = 4.04 + 1.12V \qquad (4.4)$$
$$H_{(\text{HGV - HGV})} = 9.33 + 1.21V \qquad (4.5)$$
$$H_{(\text{HGV - car})} = 5.17 + 1.19V \qquad (4.6)$$

In the above equations H is measured in meter and V is in m/s.

In general, the relationships between headway and speed found in this study are conceptually logical. All terms have a positive sign (+ve) which implies that a driver would keep a longer following distance with the leader as the speed increases. The constant could be inferred as the safe buffer distance considered by the follower, although the constants in *Equations (4.2) – (4.4)* may not represent the average length of the respective leading vehicles plus the distance at zero speed. Such a resulting short distance in the models might have been resulted from the data which might include high percentage of vehicles that are in the process of adjusting their following distance and speed after aborting overtaking manoeuvres. The coefficients, on the hand, appear to agree with a general understanding that an average driver reaction is in a range of 1 and 3 sec. The good R^2-values (i.e. greater than 0.80) for all models provide a sound basis for the acceptance of the models to represent the behaviour of the drivers on Malaysian single carriageway roads.

4.5 Comparison with other car following models and safety implications

The models of car following distance derived from this study were compared with those developed in the previous studies. Figure (4.7) shows the plots of the following distance for all vehicles together with those developed by Daou (1966), Smeed and Bennet (Lane, 1968), and the British Highway Code (Macpherson, 1993). The model obtained from this study does not differ much from those of Daou and Smeed and Bennet in terms of characteristics. The Highway Code, however, gives greater vehicle spacing at higher speed as it is based on theoretical safe braking distance under good driving conditions. It could be inferred from the comparison that, in general, most Malaysian drivers on single carriageway roads tend to follow closely their respective leading vehicles. The examinations of the current models also indicate that most drivers have a relatively shorter reaction time compared to others. This might explain the reason for most Malaysian drivers to adopt a close following behaviour.

The models for the following distance for various types of vehicles were also compared with those developed by Hunt (1997) who studied the behaviour of drivers on British single carriageway roads. The comparison is shown in Figure (4.8). The interpretations of this Figure are, again, consistent with what have been described in the preceding paragraph. The form of all models although appears similar in nature, the current models indicate that the following distances adopted by the drivers are shorter than those adopted by the British drivers, even at a relatively high speed.

The above interpretations are consistent with the typical characteristics of traffic flow on Malaysian roads where vehicles are observed to travel in platoons. Such behaviour would lead to a multiple rear-end-collision in the event of the follower failed to adjust his speed and distance with the sudden braking by the leading vehicle.

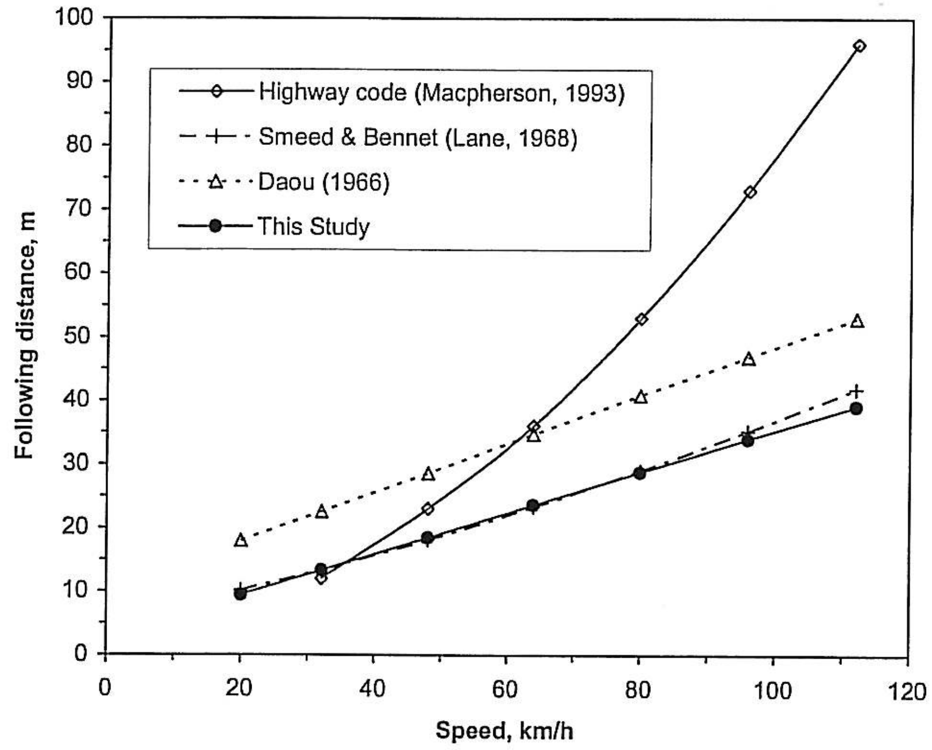

Figure 4.7: Comparison of following distance (all vehicles)

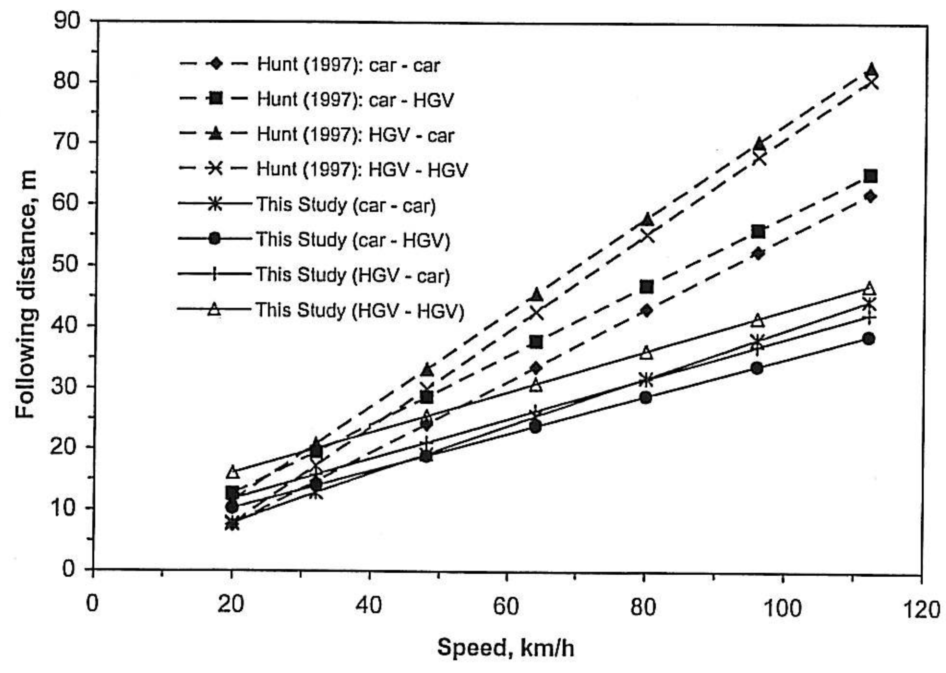

Figure 4.8: Comparison of following distance by vehicle types

4.6 Implications on speed-flow relationships

Hunt (1997) and Huddart and Lafont (1990) have demonstrated the application of the headway and speed relationships to the calculation of theoretical maximum vehicle flow at a range of speeds on an assumption that all drivers obey the appropriate car following distance model. The results of these calculations are shown in Figure (4.9). In the Figure, all computations are based on following distance for all vehicles except for the model developed by Hunt (1997). The maximum flow calculated using the respective vehicle following distance models assumes that at constant speed all vehicles maintain a constant headway. It must be pointed out here that this is a simplification of traffic operation in practice. Hunt (1997) suggested that on two-way single carriageway roads with limited overtaking opportunities some drivers may not be able to overtake, or choose not to overtake, and to fill the gaps in the traffic stream which occur from time to time. With the exception of the British Highway Code and Hunt's models, the effect of using a constant headway model which does not vary with speed is to overestimate the maximum flow of a road section, particularly at high speed.

The speed-flow relationship developed in the current study is similar to that of Smeed and Bennet. Both models do not provide a distinct appropriate maximum flow estimates for rural single carriageway roads. However, at a specified speed, both models may be used to estimate a theoretical maximum flow of a road section. For instance, a speed of about 40 km/h would provide an estimate of maximum flow which is relatively similar to the estimated maximum flow using the Highway Code model.

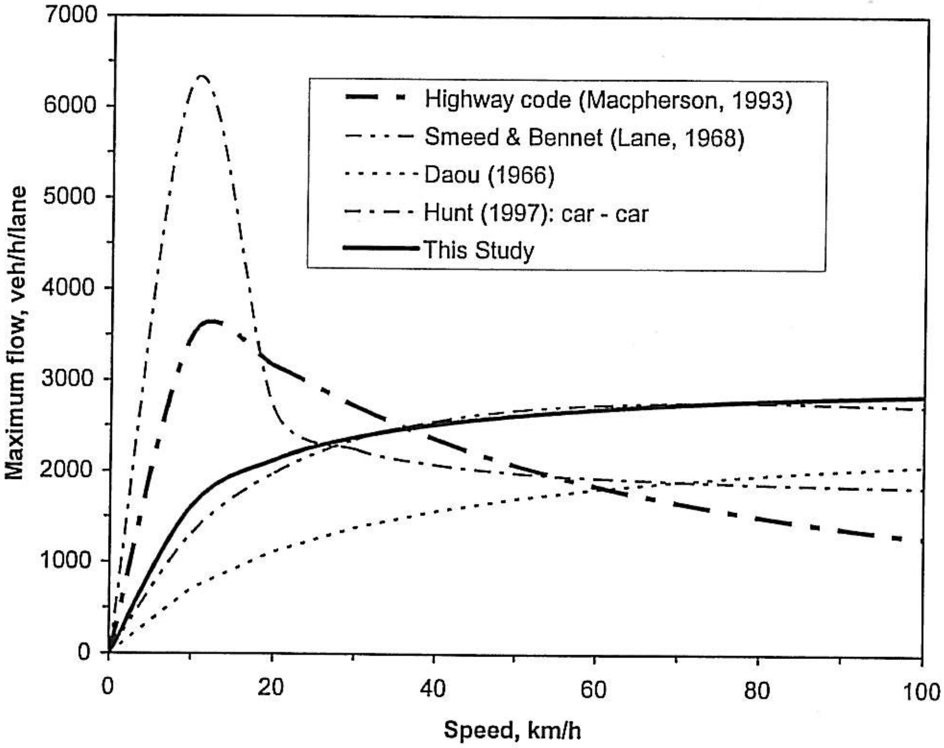

Figure 4.9: Speed-flow relationships for different headway models

4.7 Concluding remarks

This Chapter describes the results of the analysis of car following distance on Malaysian single carriageway roads. In general, the results of the study distinguished the typical car following distance of Malaysian drivers from others.

CHAPTER FIVE

CONCLUSION AND SUGGESTION

This report described the results of a study carried out on the driver's following distance on single rural carriageway roads. The study involved the collection and analysis of relatively huge amount of following headway and speed data representing some characteristics of Malaysian drivers while travelling on single carriageway roads. The following subtopics highlight several importance points and issues that may be inferred from the results of the analysis.

5.1 The findings

The analysis described in Chapter 4 has provided linear functions describing the variation in distance headway for restrained or impeded vehicles which are similar to those proposed by other researchers (e.g. Daou (1966), Mahdi (1991), and Hunt (1997)). The function describing the relationship between distance headway and speed for all vehicles is found similar to that of Smeed and Bennet (Lane, 1968) although their function is in a quadratic-formed. The functions developed in the study are:

$$H_{(\text{all vehicles})} = 2.98 + 1.16V \quad (5.1)$$

$$H_{(\text{car - car})} = 1.26 + 1.19V \quad (5.2)$$

$$H_{(\text{car - HGV})} = 4.04 + 1.12V \quad (5.3)$$

$$H_{(\text{HGV - HGV})} = 9.33 + 1.21V \quad (5.4)$$

$$H_{(\text{HGV - car})} = 5.17 + 1.19V \quad (5.5)$$

where H is the distance headway (m) and V is the vehicle speed (m/s). The empirical models derived above indicate that the following distance of a driver increases with speed. However, such models should be interpreted with cautious for a speed below 30 km/h as it would result in a following distance less than the actual length of the leading vehicle plus a safe buffer of probably not less than 1 m.

5.2 Other findings

The study described in this Report also provides some importance aspects of traffic data and the driver's behaviour on single carriageway roads. These are:

- Headway data are log normally distributed which is in agreement with the expectation.
- Most of the drivers appeared to adopt a close-following driving style. This implies that most drivers always seek opportunities to overtake the leading vehicles.
- Such a close-following distance characteristic leads to the rapid formation of vehicle platoons particularly in high traffic flows, and hence causing the road section to reach its capacity at a faster rate.
- The risk of road crashes is high on a single carriageway road because of close-following distance adopted by most drivers.

5.3 Suggestions for further works

The result of this study has shown that the following distance headway varies with the follower speed. The empirical models were developed based on relatively large sample size of drivers. However, the consideration of variation in road geometry during data collection has been limited. Such a limitation might lead to an argument that the models developed may not representative of drivers' characteristics oh various types of road sections.

It is suggested that a further study is carried out to consider the following aspects:

- The headway and speed data for the drivers on other road geometry, i.e. such as drivers on road sections classified as hilly or bendy, or the combination of both.
- The study should also include measurements at a series of locations about 100 m apart on single carriageway roads which are operating near capacity.

- The study should also include measurements of headway data for vehicles seeking an accelerative overtaking manoeuvre.

5.4 Concluding remarks

The study has achieved its aim and objectives as described in Chapter 1. Empirical models of vehicle following distance on single carriageway roads were developed in this study. The models describe the some importance characteristics of Malaysian drivers on single carriageway roads. The models also provide evidences of level of aggressiveness of Malaysian drivers. Further study is essential to include headway data defining driver behaviour on hilly and bendy road sections.

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APPENDIX A – Distribution of impeded vehicle headways by speed class

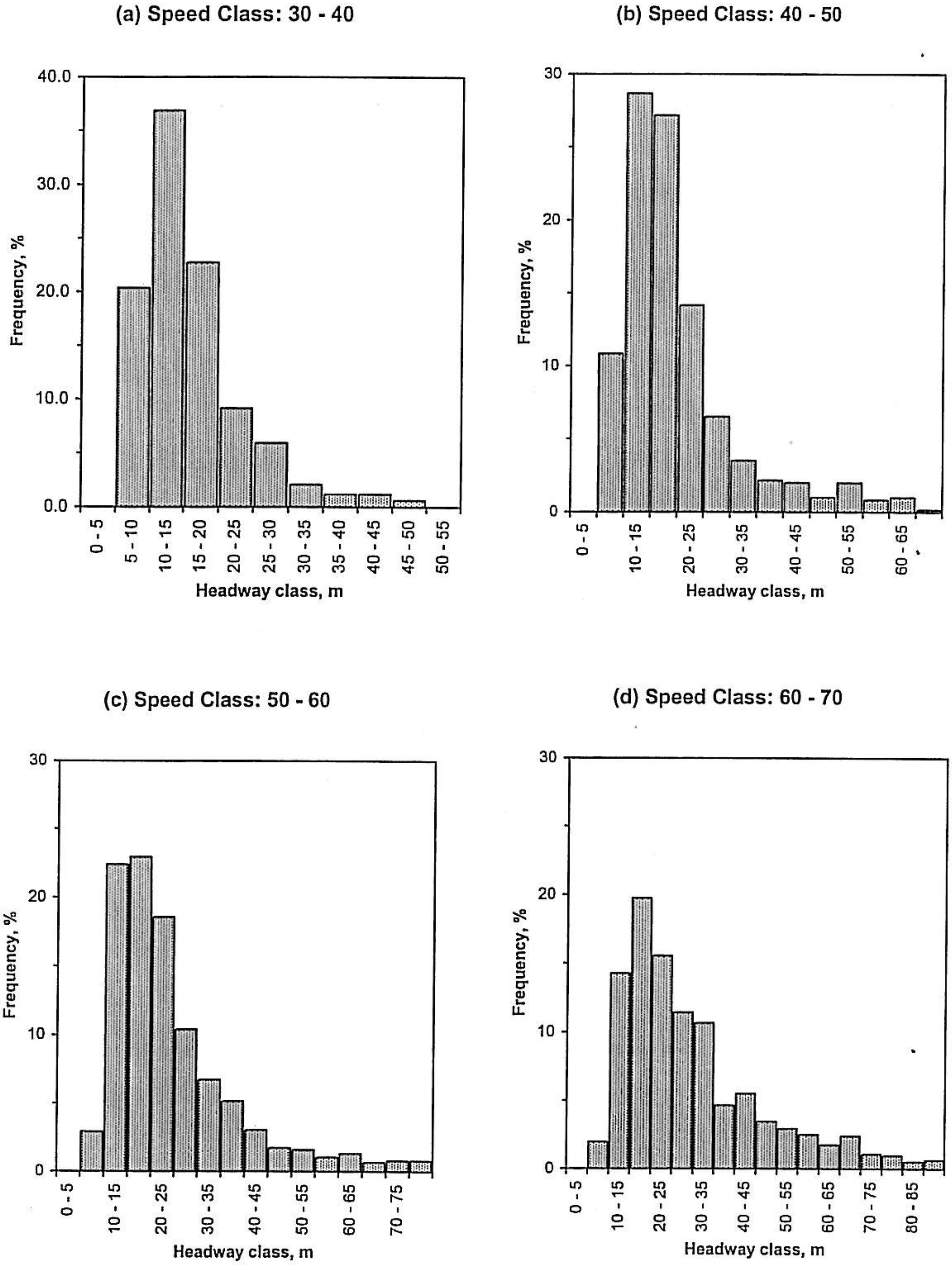


Figure A.1: Distribution of impeded vehicle headways by speed class for all vehicles

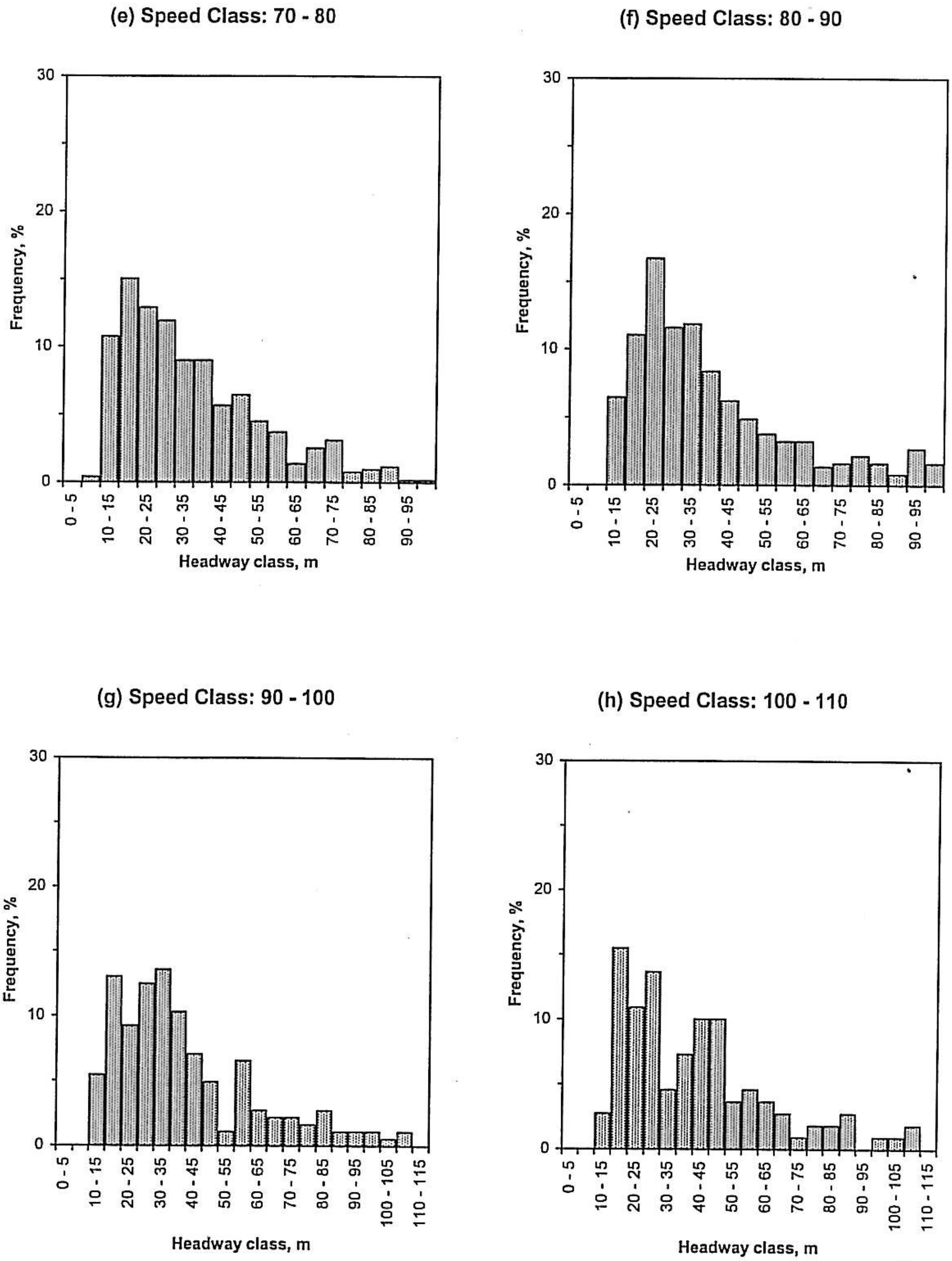


Figure A.1: (Cont'd)

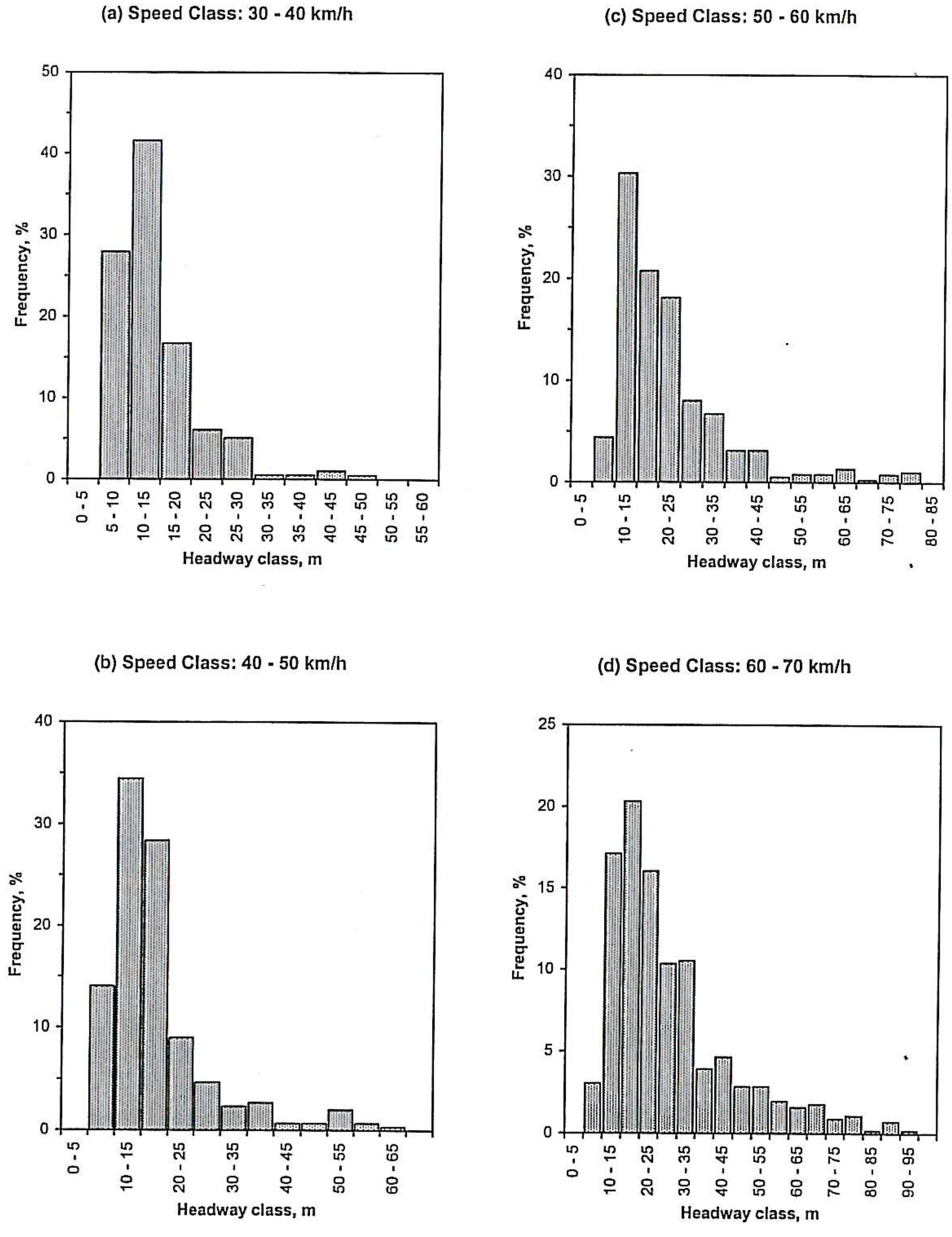


Figure A.2: Distribution of impeded vehicle headways by speed class for car following car

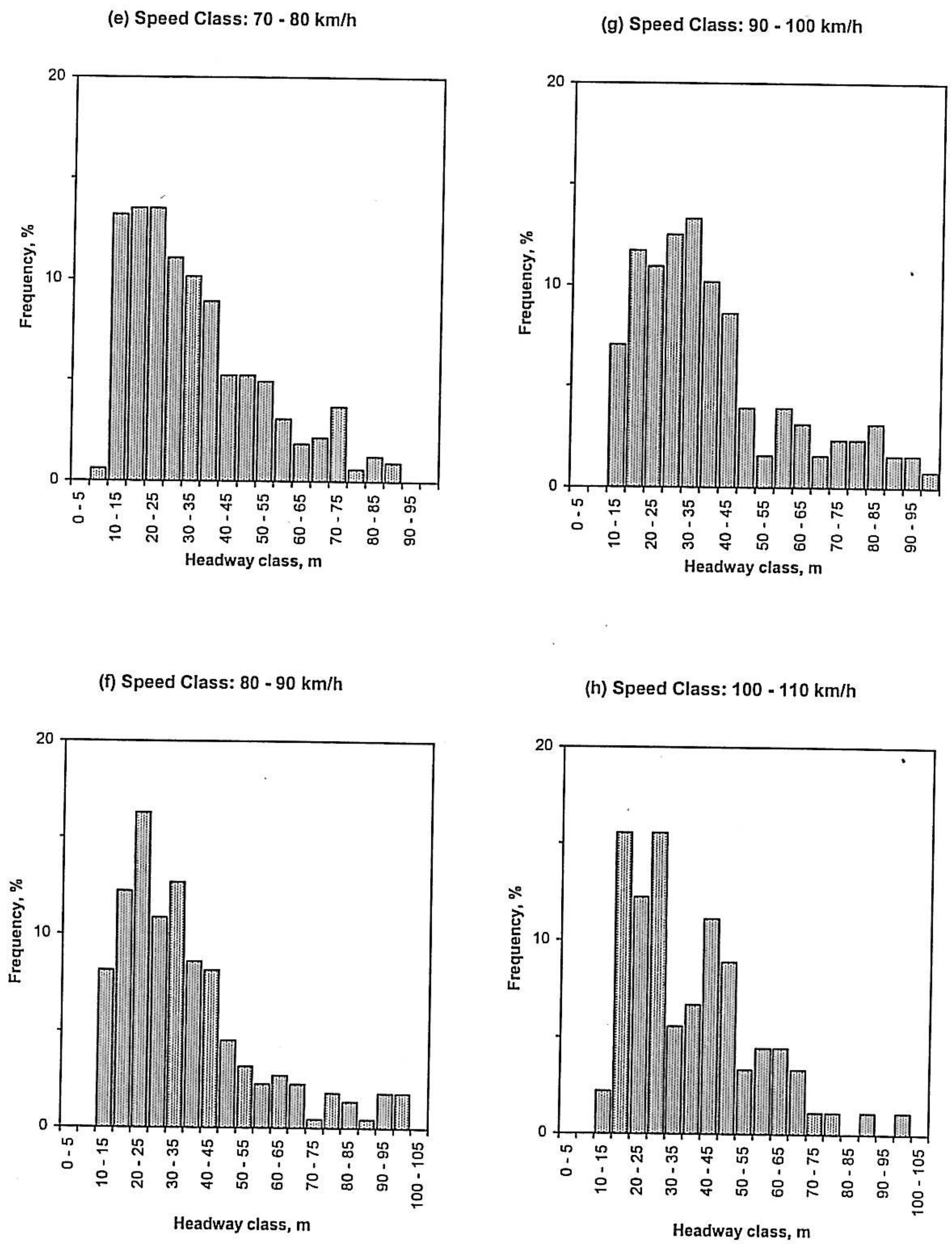


Figure A.2: (Cont'd)

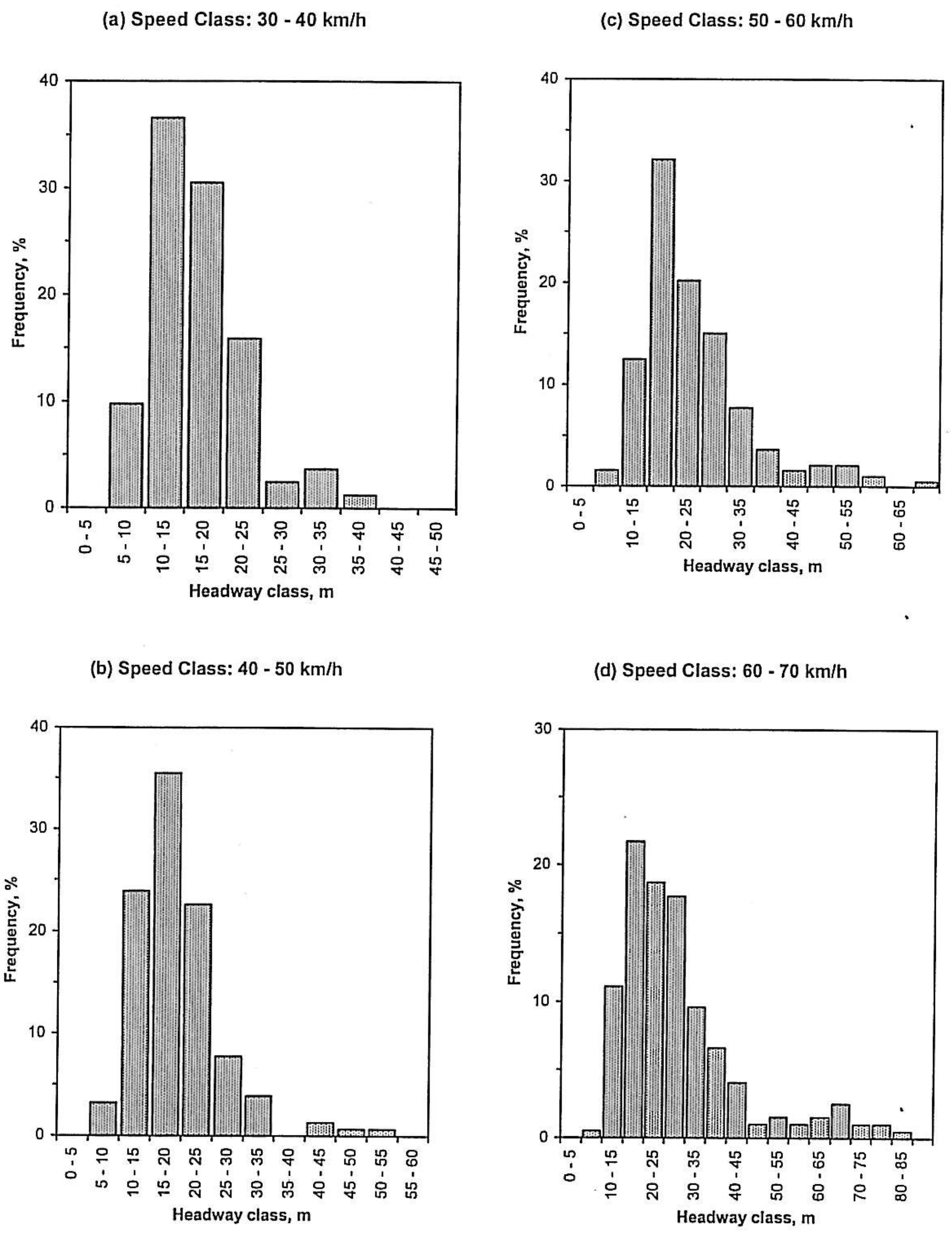
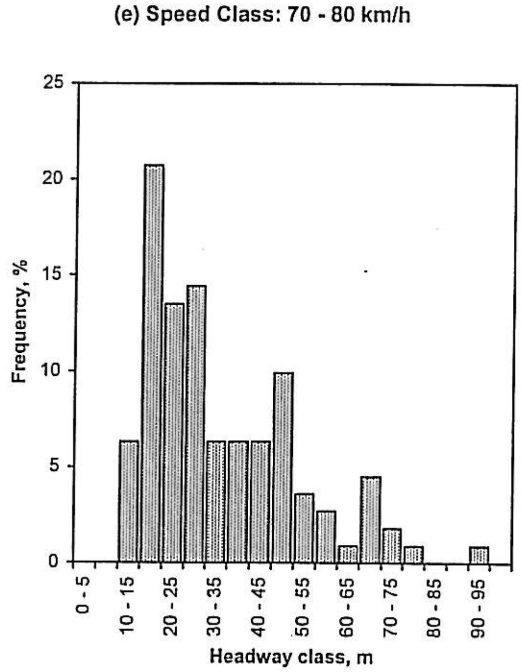
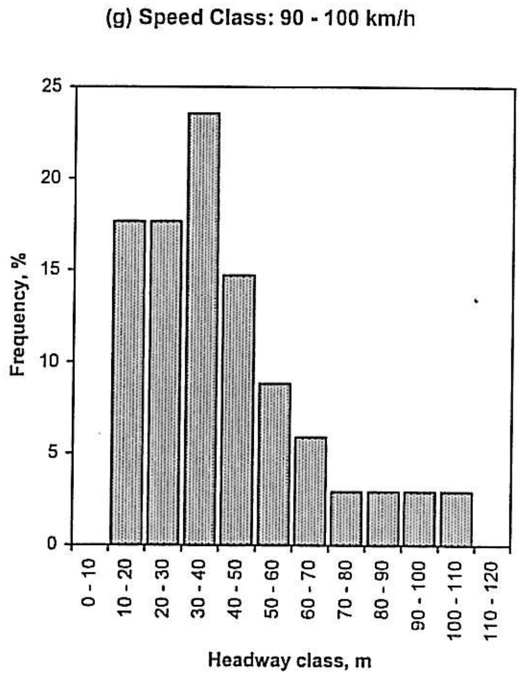


Figure A.3: Distribution of impeded vehicle headways by speed class for car following HGV





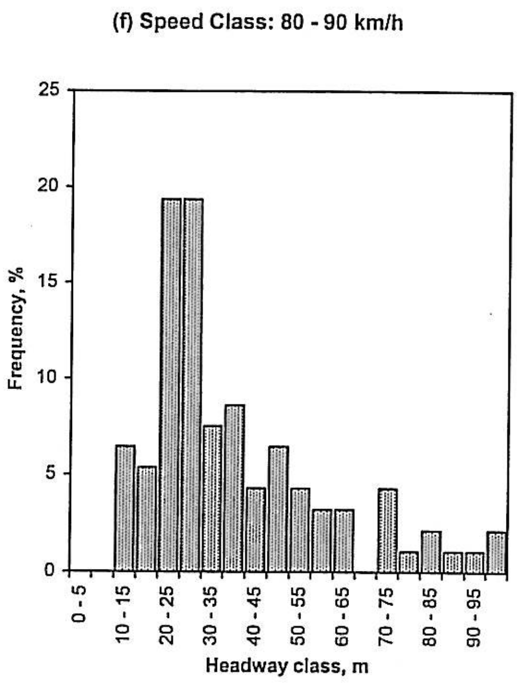


Figure A.3: (Cont'd)

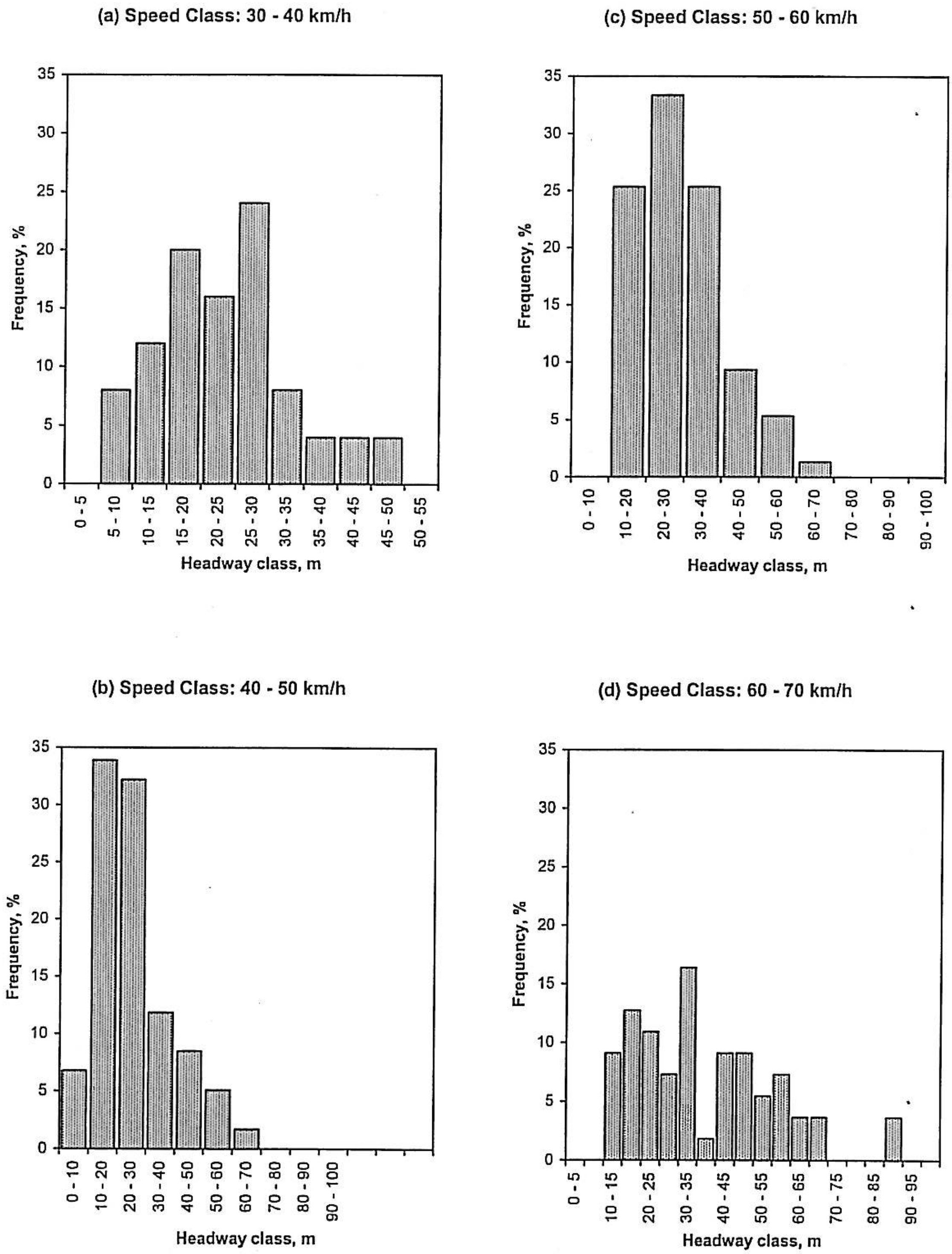


Figure A.4: Distribution of impeded vehicle headways by speed class for HGV following HGV

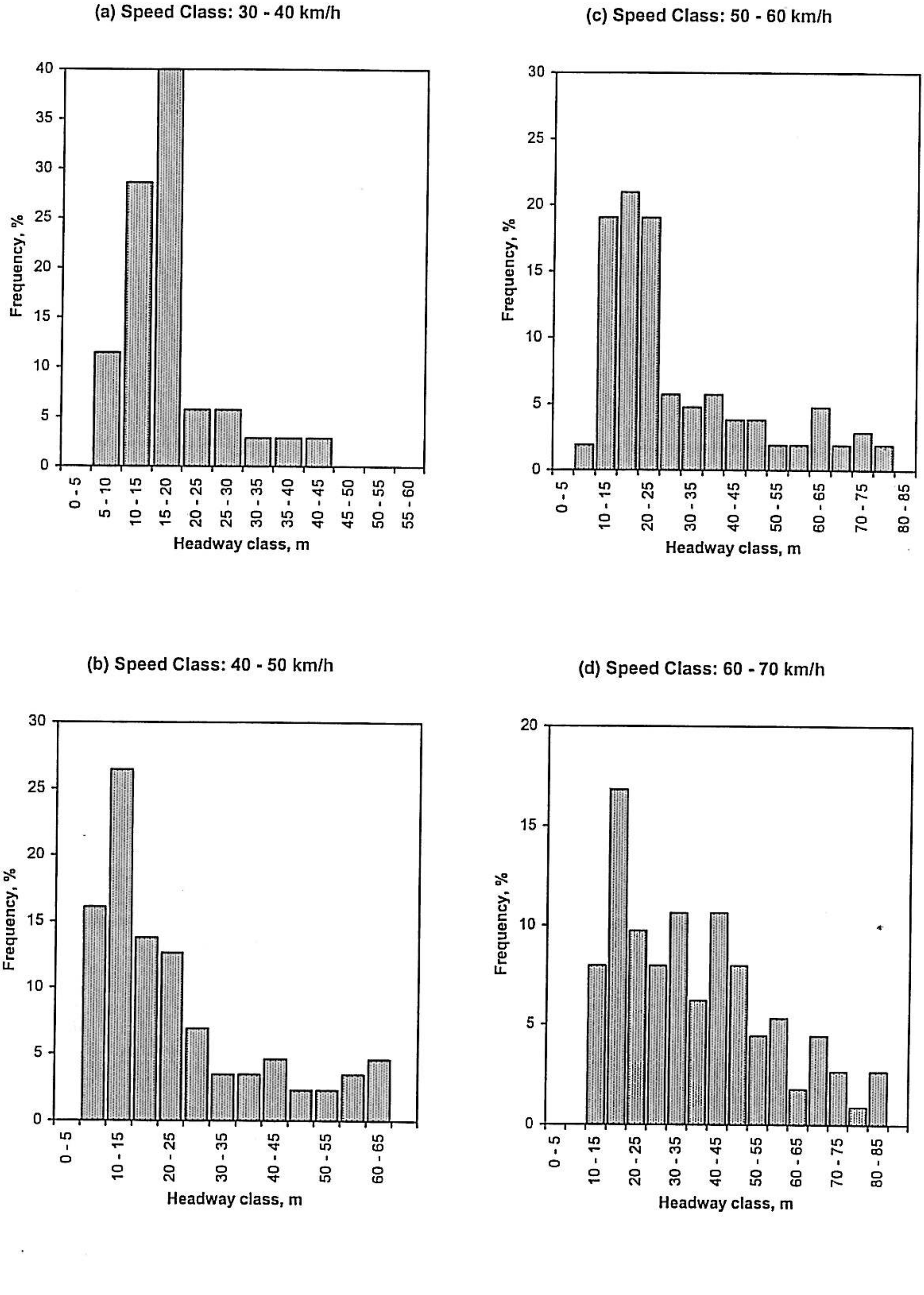


Figure A.5: Distribution of impeded vehicle headways by speed class for HGV following car

APPENDIX B – Descriptive statistics for headway and speed data

Table B.1: Descriptive statistics for all vehicles

Speed Class - km/h	20 - 30	30 - 40	40 - 50	50 - 60	60 – 70	70 - 80	80 - 90	90 - 100	100 - 110	110 - 120
Headways – sec										
Mean	1.58	1.53	1.56	1.56	1.64	1.68	1.63	1.50	1.40	1.36
Standard Error	0.17	0.04	0.03	0.03	0.03	0.04	0.05	0.06	0.07	0.09
Median	1.40	1.38	1.35	1.30	1.38	1.44	1.34	1.28	1.25	1.18
Mode	1.64	1.35	0.93	0.77	0.83	0.99	0.72	1.05	1.01	1.15
Standard Deviation	0.67	0.70	0.85	0.86	0.92	0.93	0.94	0.83	0.77	0.71
Sample Variance	0.45	0.49	0.72	0.74	0.85	0.86	0.89	0.69	0.60	0.50
Kurtosis	7.12	3.44	3.35	3.03	1.41	1.47	0.91	0.75	0.85	1.87
Skewness	2.49	1.65	1.80	1.71	1.33	1.17	1.24	1.16	1.14	1.38
Range	2.77	3.96	4.51	4.53	4.48	5.97	4.37	3.63	3.42	3.15
Minimum	0.91	0.55	0.49	0.47	0.41	0.44	0.44	0.44	0.46	0.41
Maximum	3.68	4.50	5.00	5.00	4.89	6.40	4.81	4.07	3.88	3.57
Headways - meter										
Mean	11.55	15.64	19.68	24.02	29.52	34.54	38.17	39.31	40.85	43.43
Standard Error	0.93	0.39	0.45	0.49	0.55	0.84	1.14	1.59	2.14	2.88
Median	10.87	14.09	16.90	20.38	24.64	29.64	31.58	33.56	36.33	37.95
Mode	11.54	8.59	10.00	36.36	12.50	14.44	20.57	35.70	#N/A	#N/A
Standard Deviation	3.62	7.25	10.99	13.38	16.74	19.11	22.00	21.63	22.40	22.66
Sample Variance	13.09	52.58	120.77	179.15	280.36	365.25	483.89	468.07	501.85	513.62
Kurtosis	2.02	3.48	3.80	3.19	1.33	1.35	0.86	0.73	0.80	2.18
Skewness	1.51	1.64	1.89	1.73	1.31	1.16	1.23	1.14	1.12	1.43
Range	12.30	43.83	58.74	72.64	83.64	117.73	102.36	94.29	95.13	103.18
Minimum	7.48	5.68	6.30	6.86	7.45	9.35	10.57	11.43	14.02	12.73
Maximum	19.78	49.51	65.04	79.50	91.10	127.08	112.93	105.71	109.15	115.91
Speed - km/h										
Mean	27.06	36.85	45.20	55.51	64.82	74.22	84.39	94.40	104.97	115.47
Standard Error	0.80	0.13	0.11	0.10	0.09	0.12	0.15	0.19	0.33	0.46
Median	28.30	37.31	45.28	56.25	65.23	74.20	84.52	93.51	104.52	116.88
Mode	25.26	36.36	46.75	59.50	60.81	74.38	80.33	93.51	109.09	116.88
Standard Deviation	3.10	2.43	2.73	2.81	2.80	2.62	2.88	2.52	3.49	3.62
Sample Variance	9.59	5.89	7.45	7.90	7.84	6.89	8.31	6.33	12.21	13.08
Kurtosis	1.81	-0.37	-1.15	-1.09	-1.25	-1.39	-1.45	-1.08	-1.55	-1.55
Skewness	-1.35	-0.68	0.03	-0.24	-0.04	0.20	0.07	0.28	0.16	-0.47
Count	15	339	600	759	927	512	371	184	110	62

Table B.2: Descriptive statistics for car following car

Speed Class - km/h	30 - 40	40 - 50	50 – 60	60 - 70	70 - 80	80 - 90	90 - 100	100 - 110	110 - 120
Headways – sec									
Mean	1.37	1.41	1.42	1.54	1.64	1.53	1.46	1.33	1.38
Standard Error	0.05	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.10
Median	1.21	1.19	1.18	1.29	1.43	1.32	1.27	1.09	1.21
Mode	1.21	0.93	0.77	0.99	1.13	0.88	0.99	1.01	1.15
Standard Deviation	0.64	0.76	0.83	0.90	0.92	0.87	0.81	0.72	0.75
Sample Variance	0.41	0.57	0.69	0.80	0.86	0.76	0.65	0.51	0.56
Kurtosis	6.47	4.64	4.73	1.91	1.80	1.43	0.48	2.06	1.45
Skewness	2.12	2.04	2.03	1.46	1.20	1.35	1.10	1.39	1.34
Range	3.96	4.06	4.53	4.45	5.97	3.93	3.33	3.42	3.15
Minimum	0.55	0.49	0.47	0.41	0.44	0.44	0.44	0.46	0.41
Maximum	4.50	4.56	5.00	4.86	6.40	4.37	3.76	3.88	3.57
Headways - meter									
Mean	13.93	17.73	22.00	27.85	33.83	35.98	38.21	38.66	44.21
Standard Error	0.47	0.57	0.66	0.69	1.05	1.39	1.84	2.17	3.36
Median	12.43	15.32	18.15	23.26	29.45	31.14	32.84	32.33	39.10
Mode	8.59	16.97	16.18	12.50	14.44	20.57	#N/A	#N/A	#N/A
Standard Deviation	6.61	9.78	13.03	16.32	18.96	20.65	20.82	20.63	24.01
Sample Variance	43.66	95.66	169.77	266.31	359.30	426.23	433.33	425.42	576.65
Kurtosis	6.38	4.96	5.21	1.96	1.53	1.45	0.32	1.92	1.79
Skewness	2.10	2.11	2.11	1.47	1.17	1.36	1.05	1.34	1.41
Range	43.83	55.32	72.64	83.64	117.73	94.47	83.65	95.13	103.18
Minimum	5.68	6.30	6.86	7.45	9.35	10.58	11.43	14.02	12.73
Maximum	49.51	61.62	79.50	91.10	127.08	105.05	95.08	109.15	115.91
Speed - km/h									
Mean	36.59	45.30	55.59	64.83	74.21	84.37	94.25	104.88	115.37
Standard Error	0.18	0.15	0.14	0.12	0.15	0.19	0.22	0.36	0.51
Median	36.82	45.28	56.25	65.23	74.38	84.52	93.51	104.52	116.88
Mode	36.36	43.64	58.44	60.81	74.38	81.82	93.51	109.09	116.88
Standard Deviation	2.48	2.67	2.78	2.84	2.63	2.81	2.52	3.45	3.67
Sample Variance	6.16	7.14	7.74	8.09	6.90	7.87	6.37	11.93	13.45
Kurtosis	-0.67	-1.09	-1.04	-1.30	-1.37	-1.49	-0.99	-1.50	-1.62
Skewness	-0.51	-0.05	-0.32	-0.05	0.25	0.12	0.32	0.25	-0.38
Count	197	299	386	561	326	221	128	90	51

Table B.3: Descriptive statistics for car following HGV

Speed Class - km/h	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 – 100
Headways – sec							
Mean	1.59	1.54	1.52	1.56	1.64	1.62	1.57
Standard Error	0.06	0.05	0.05	0.06	0.08	0.09	0.15
Median	1.48	1.45	1.38	1.38	1.37	1.27	1.25
Mode	1.43	1.64	1.49	1.24	0.99	1.57	1.05
Standard Deviation	0.54	0.61	0.67	0.80	0.88	0.89	0.86
Sample Variance	0.30	0.37	0.45	0.64	0.77	0.79	0.74
Kurtosis	2.32	8.09	3.72	3.06	1.38	0.89	0.72
Skewness	1.32	2.24	1.74	1.70	1.21	1.23	1.11
Range	2.75	4.18	3.98	4.18	4.40	3.76	3.36
Minimum	0.74	0.71	0.52	0.49	0.52	0.47	0.57
Maximum	3.49	4.89	4.50	4.67	4.92	4.23	3.93
Headways – meter							
Mean	16.56	19.45	23.45	28.12	33.97	37.95	41.41
Standard Error	0.64	0.63	0.73	1.04	1.75	2.11	3.89
Median	15.30	18.18	20.91	24.46	28.04	29.82	33.04
Mode	#N/A	10.57	16.89	20.97	#N/A	#N/A	#N/A
Standard Deviation	5.77	7.88	10.21	14.62	18.39	20.36	22.67
Sample Variance	33.32	62.15	104.24	213.60	338.14	414.73	514.10
Kurtosis	2.48	8.37	2.93	2.66	1.89	0.83	0.82
Skewness	1.37	2.23	1.59	1.66	1.30	1.20	1.15
Range	29.41	55.26	57.63	72.78	95.79	85.57	86.74
Minimum	7.91	8.41	7.66	9.37	11.06	10.57	15.29
Maximum	37.33	63.67	65.29	82.16	106.85	96.14	102.03
Speed - km/h							
Mean	37.46	45.39	55.51	64.85	74.49	84.58	94.99
Standard Error	0.25	0.22	0.20	0.19	0.25	0.31	0.44
Median	37.97	45.28	55.23	65.45	74.38	84.52	93.51
Mode	38.50	46.75	59.50	60.81	74.38	80.33	93.51
Standard Deviation	2.23	2.72	2.79	2.71	2.61	3.01	2.55
Sample Variance	4.96	7.42	7.78	7.32	6.82	9.04	6.49
Kurtosis	0.99	-1.16	-1.19	-1.10	-1.36	-1.42	-1.37
Skewness	-1.16	0.07	-0.13	-0.13	-0.01	-0.06	-0.04
Count	82	155	193	198	111	93	34

Table B.4: Descriptive statistics for HGV following HGV

Speed Class - km/h	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
Headways – sec							
Mean	2.31	2.01	1.91	2.04	2.20	1.98	1.46
Standard Error	0.19	0.13	0.09	0.14	0.22	0.19	0.14
Median	2.14	1.82	1.79	1.79	1.87	1.70	1.41
Mode	#N/A	1.07	1.10	1.73	#N/A	#N/A	#N/A
Standard Deviation	0.94	0.98	0.74	1.03	1.22	0.87	0.50
Sample Variance	0.87	0.95	0.55	1.07	1.48	0.76	0.25
Kurtosis	-0.13	0.13	-0.12	0.34	-0.50	-0.25	-0.57
Skewness	0.58	0.86	0.58	0.81	0.70	0.69	0.44
Range	3.49	4.34	3.29	4.31	4.34	3.13	1.59
Minimum	0.91	0.52	0.72	0.58	0.58	0.86	0.69
Maximum	4.40	4.87	4.01	4.89	4.91	3.98	2.28
Headways – meter							
Mean	23.55	24.90	29.38	36.72	45.00	45.82	38.58
Standard Error	1.92	1.63	1.40	2.49	4.47	4.36	4.07
Median	21.73	21.81	26.90	32.21	38.79	38.75	36.68
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	9.61	12.50	12.09	18.43	24.88	19.97	14.12
Sample Variance	92.43	156.30	146.20	339.74	618.81	398.67	199.24
Kurtosis	0.22	0.93	0.12	0.09	-0.69	-0.62	-0.62
Skewness	0.67	1.07	0.67	0.75	0.67	0.58	0.49
Range	37.26	58.68	55.46	74.46	83.69	69.84	44.75
Minimum	9.75	6.36	10.82	11.03	12.47	19.08	17.30
Maximum	47.01	65.04	66.28	85.49	96.16	88.92	62.05
Speed - km/h							
Mean	36.82	44.38	55.11	65.00	73.92	83.13	94.46
Standard Error	0.54	0.39	0.35	0.35	0.47	0.61	0.79
Median	37.19	43.64	54.55	65.45	73.64	81.82	93.51
Mode	36.36	40.91	59.50	65.69	70.43	80.33	98.18
Standard Deviation	2.70	2.97	3.02	2.61	2.64	2.78	2.73
Sample Variance	7.31	8.81	9.13	6.79	6.97	7.72	7.47
Kurtosis	-0.68	-1.20	-1.20	-1.08	-1.56	-0.86	-1.35
Skewness	-0.72	0.38	0.01	-0.15	0.20	0.71	0.33
Count	25	59	75	55	31	21	12

Table B.5: Descriptive statistics for HGV following car

Speed Class - km/h	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
				Headways - sec			
Mean	1.70	1.84	1.86	2.05	1.66	2.03	1.79
Standard Error	0.12	0.13	0.11	0.10	0.11	0.22	0.40
Median	1.59	1.40	1.37	1.82	1.62	1.44	1.27
Mode	1.60	1.49	1.37	1.27	0.85	0.77	#N/A
Standard Deviation	0.72	1.21	1.17	1.05	0.76	1.32	1.28
Sample Variance	0.52	1.46	1.37	1.10	0.57	1.75	1.63
Kurtosis	1.80	0.43	0.31	-0.21	-0.45	-0.86	-0.15
Skewness	1.34	1.22	1.20	0.73	0.56	0.72	1.07
Range	3.02	4.48	4.20	4.24	2.80	4.18	3.49
Minimum	0.71	0.52	0.63	0.60	0.66	0.63	0.58
Maximum	3.74	5.00	4.83	4.84	3.46	4.81	4.07
				Headways - meter			
Mean	17.45	23.25	28.63	36.80	33.91	47.73	47.16
Standard Error	1.29	1.69	1.75	1.76	2.36	5.16	10.82
Median	16.92	17.61	21.35	32.77	32.28	33.02	33.04
Mode	#N/A	10.00	16.76	31.88	38.39	58.89	#N/A
Standard Deviation	7.62	15.75	17.97	18.72	15.62	30.96	34.22
Sample Variance	58.08	248.04	322.89	350.57	244.04	958.68	1171.07
Kurtosis	2.30	0.59	0.35	-0.29	-0.17	-0.97	-0.19
Skewness	1.40	1.28	1.20	0.69	0.66	0.69	1.07
Range	34.05	57.48	66.42	74.20	60.57	97.56	90.78
Minimum	6.99	6.75	9.13	10.73	13.10	15.37	14.94
Maximum	41.04	64.24	75.55	84.92	73.67	112.93	105.71
				Speed - km/h			
Mean	36.84	45.07	55.53	64.60	73.76	84.78	94.33
Standard Error	0.37	0.29	0.27	0.27	0.40	0.50	0.65
Median	36.55	45.28	56.25	63.38	73.64	84.52	93.48
Mode	36.36	46.75	59.50	62.61	71.43	80.33	93.46
Standard Deviation	2.19	2.71	2.81	2.85	2.63	3.00	2.05
Sample Variance	4.82	7.35	7.91	8.13	6.91	8.98	4.20
Kurtosis	0.73	-1.21	-0.94	-1.26	-1.38	-1.36	1.27
Skewness	-0.73	0.04	-0.31	0.21	0.37	-0.17	1.69
Count	35	87	105	113	44	36	10

APPENDIX C – Regressions analysis for following distance data by vehicle types

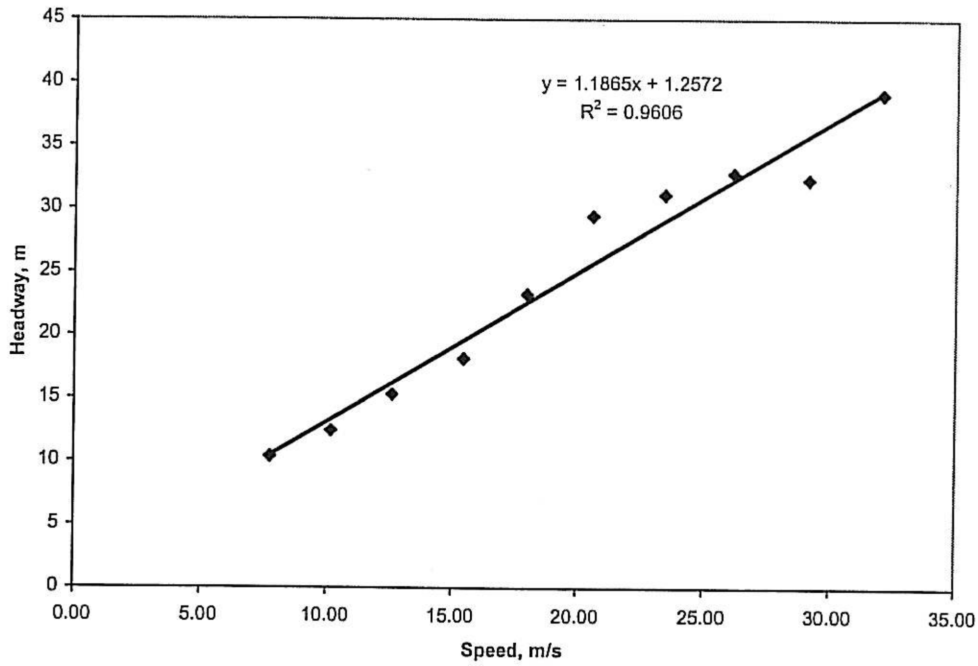


Figure C.1(a): Headway and mean speed for each speed class (car following car)

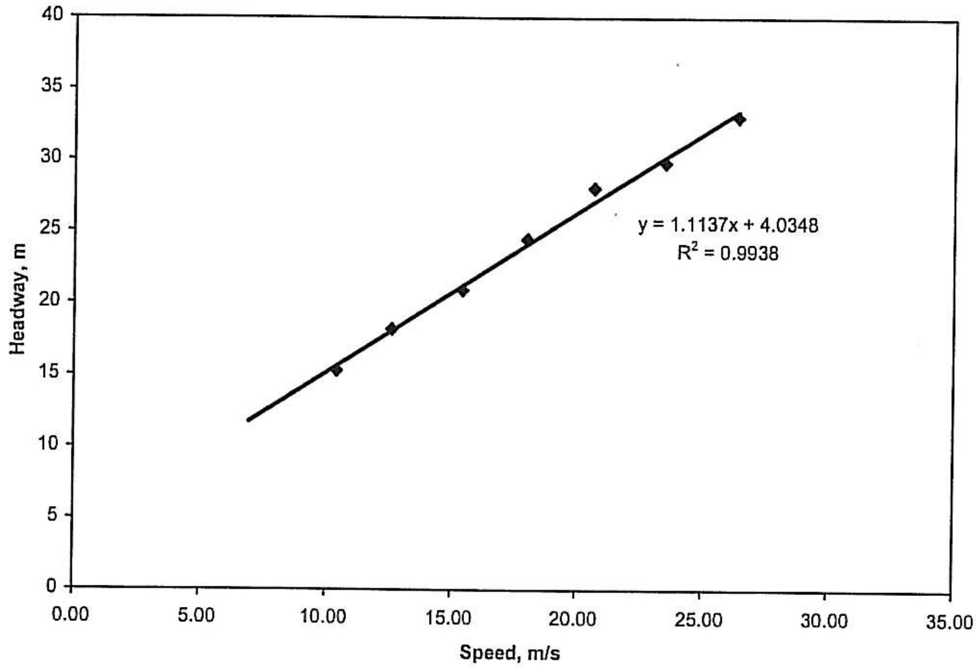


Figure C.1(b): Headway and mean speed for each speed class (car following HGV)

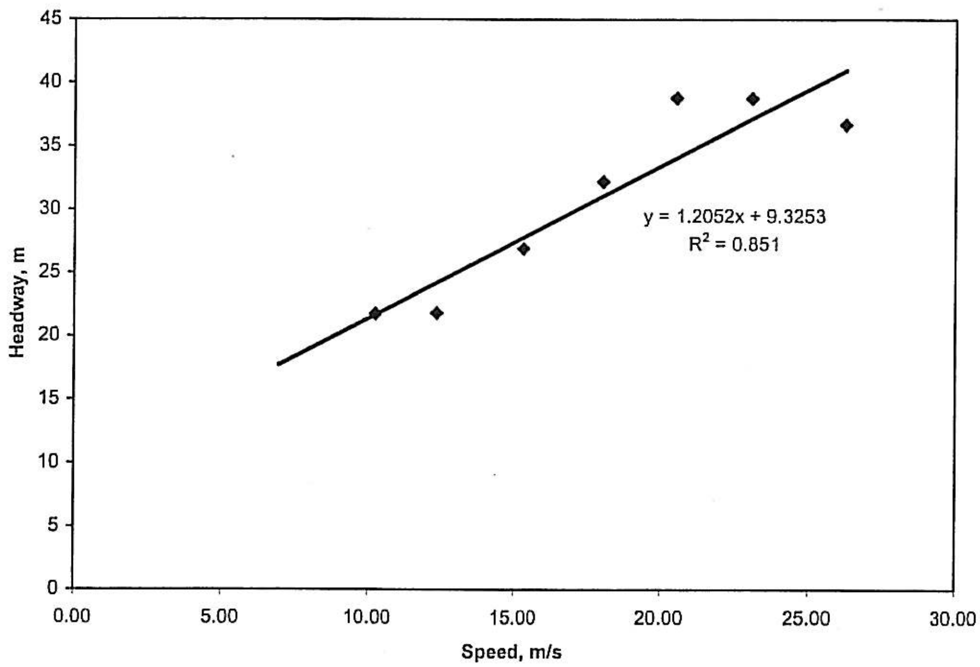


Figure C.1(c): Headway and mean speed for each speed class (HGV following HGV)

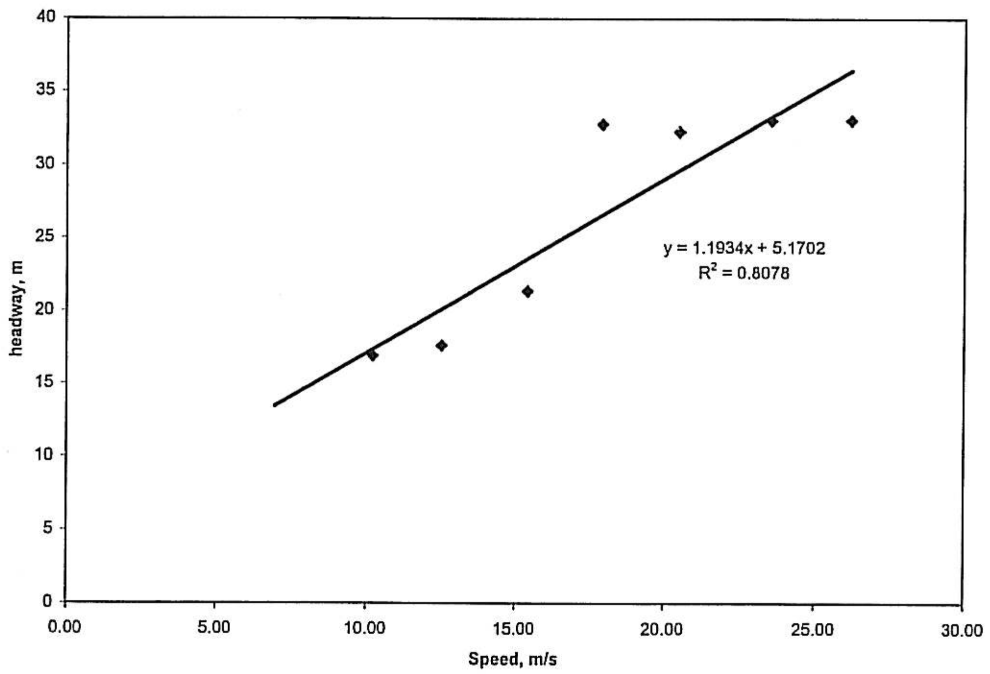


Figure C.1(d): Headway and mean speed for each speed class (HGV following car)